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MEMORANDUM REPORT
NO. 1664

SOME AERODYNAMIC EFFECTS OF VARYING THE BODY LENGTH AND HEAD LENGTH OF A SPINNING PROJECTILE

By Elizabeth R. Dickinson

JULY 1965

U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1664

JULY 1965

SOME AERODYNAMIC EFFECTS OF VARYING THE BODY LENGTH AND HEAD LENGTH OF A SPINNING PROJECTILE

Elizabeth R. Dickinson

Computing Laboratory

RDT & E Project No. 1P523001A287

ABERDEEN PROVING GROUND, MARYLAND

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MEMORANDUM REPORT NO. 1664

ERDickinson/vc
Aberdeen Proving Ground, Md.
July 1965

SOME AERODYNAMIC EFFECTS OF VARYING THE BODY LENGTH AND HEAD LENGTH OF A SPINNING PROJECTILE

ABSTRACT

Experimental results are presented on the effect, at supersonic velocities, on the drag coefficient, overturning moment coefficient, normal force coefficient and center of pressure, of varying the head length and the body length of spinning projectiles.

I. INTRODUCTION

Murphy and Schmidt investigated the effect on aerodynamic coefficients of varying the length of a cylindrical body attached to an ogival head two calibers in length.[1,2]* The cylindrical bodies were three, five and seven calibers in length. In addition, a theoretical study was made of projectile shapes which covered body lengths of one and one-half to three calibers[3]. It seemed desirable to make an experimental check on the results of the theoretical work on short bodies, to find the effect of shortening the body still more, and to investigate the effect of shortening the body of a projectile with a longer ogive than that of References 1 and 2.

Twenty-millimeter models were fired, in the free flight range[4] of the Ballistic Research Laboratories, with 2- and 3-caliber ogives and with cylindrical bodies of various lengths (Fig. 1). All of the rounds were fired at one Mach number, 1.8. The results of Reference 1 were incorporated with the results of the present investigation to show some aerodynamic effects of shortening the body of a projectile.

In addition, models were fired, at M 1.8, to determine the aerodynamic effects of varying the head length of projectiles, both with a constant overall length and with a constant body length (Fig. 2). The results of References 5 and 6 were incorporated with those of the present investigation.

*Superscript numbers denote references found on page 10.

II. RESULTS

Drag

The drag coefficients for all rounds were reduced to zero-yaw drag coefficients by means of the following relationship.

$$C_D = C_{D_o} + C_{D_{\delta^2}} \overline{\delta^2}$$

where C_D = observed drag coefficient

C_{D_o} = zero-yaw drag coefficient

$C_{D_{\delta^2}}$ = yaw drag coefficient in radians^{-2} = 6.6

$\overline{\delta^2}$ = mean squared yaw in radians^2

Although all rounds fired were at a nominal velocity of M = 1.8, there were of course small variations in velocity. Hence, all zero-yaw drag coefficients were then corrected to a Mach number of 1.8, by means of a Q-function slope.

$$\sqrt{C_{D_o} M_i^2 + 8/\pi} = Q_o(M_i) = a + bM_i$$

$$Q_o(M_i) + b(1.8-M_i) = Q_o(1.8)$$

$$C_{D_o}(1.8) = \frac{Q_o^2(1.8) - 8/\pi}{1.8^2}$$

where b = 1.596

Reference 1 showed that for body lengths increasing from three to seven calibers the total drag increase could be accounted for by the increase in skin friction drag. The present investigation showed that minimum drag occurred with a body length of about one and one-half calibers (Fig. 3). Base pressure must therefore be more sensitive to variations in length of short bodies than to variations in length of long bodies. Base pressures were calculated by the method of Reference 7 and are shown in Figure 4. The corresponding base drag coefficients were then calculated.

$$C_{DB} = \left(\frac{2}{\gamma M^2}\right)\left(\frac{d_b}{d}\right)^2\left(1 - \frac{P_b}{P_o}\right)$$

where C_{DB} = base drag coefficient

γ = ratio of specific heats of air = 1.405

M = Mach number

d_b = base diameter (= d for these projectiles)

d = body diameter

P_b/P_o = base pressure/free stream pressure.

The base drag shown in Figure 5 does indeed vary much more rapidly for short body lengths and becomes relatively insensitive to an increase in length beyond three to four calibers.

Skin friction drag coefficients for the bodies of the projectiles were calculated by means of the following:

$$C_{DSF} = \frac{4}{\pi} A \ C_f = 4 \ell C_f$$

where, A = wetted surface area, in calibers

ℓ = length of body, in calibers

C_f (cylinder) = $k\,C_f$ (flat plate)

k = Chapman-Kester coefficient from NACA TN 3097

$$C_f \text{ (flat plate-turbulent)} = \frac{.455}{(\log_{10} Re)^{2.58}}$$

$$Re = \text{Reynolds number} = \frac{\rho V \ell}{\mu}$$

ρ = air density (lb/ft^3)

V = projectile velocity (ft/sec)

ℓ = body length (ft)

μ = viscosity (lb/ft-sec).

With only body length added, head drag remains constant while skin friction drag increases and base drag decreases. There must, therefore, be a minimum total drag at some body length. Head drag can be computed by the method of characteristics. This computation was made and the results included in Reference 1.

The theoretical values for base drag, head drag, turbulent skin friction drag and their sum, or total drag, are shown in Figure 6, together with the experimental values for total drag. All of the curves in this figure were computed for a projectile with a 2-caliber, secant ogive and a square-based, cylindrical body. The general character of the theoretical curve for total drag is similar to that of the experimental curve, in that there is a minimum; the agreement between the two curves, however, is only fair. It is probable that the principal cause of the discrepancy is the inadequacy of the estimates of base pressure, particularly for short bodies.

The effect on drag of increasing the head length is as expected (Fig. 7). For models with either a constant overall length or a constant body length, the drag coefficient decreases with increasing head length.

Overturning Moment Coefficient, Normal Force Coefficient and Center of Pressure

From the data available, it was possible to obtain the above aerodynamic parameters only for the models with the 2- and 3-caliber secant ogives. Several of these configurations were fired with more than one location of the center of gravity, thus making it possible to obtain the normal force coefficient ($C_{N\alpha}$) from the slope of the moment coefficient ($C_{M\alpha}$) versus center of gravity relationship (Fig. 8). $C_{N\alpha}$ was also obtained directly from the swerve reductions. The agreement between these two methods of determining $C_{N\alpha}$ was very good (Fig. 9). For body lengths greater than 2 calibers, $C_{N\alpha}$ is essentially a constant. The center of pressure of the normal force is plotted against body length in Figure 10.

In order to make a comparison of the moment coefficients for the various lengths of projectiles fired, the observed moment coefficients were transferred to moment coefficients with the centers of gravity at the base of each model. These modified moment coefficients are plotted against body length in Figure 11. For body lengths greater than one caliber, the overturning moment coefficient about the base is a linear function of body length.

ELIZABETH R. DICKINSON

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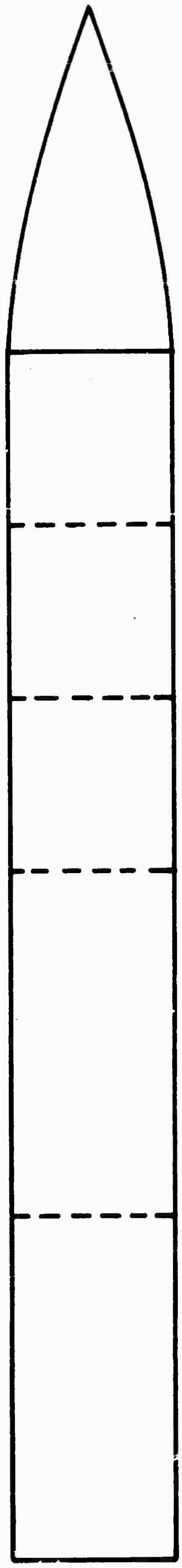
TYPES OF PROJECTILES
WITH
SECANT OGIVES AND VARYING BODY LENGTHS



HEAD LENGTH (CAL.)	BODY LENGTH (CAL.)	OVERALL LENGTH (CAL.)
2	0	2
2	1	3
2	2	4
2 *	3 *	5 *
2 *	5 *	7 *
2 *	7 *	9 *
3	0	3
3	1	4
3	2	5
3	3	6
3	4	7

* REF. 1

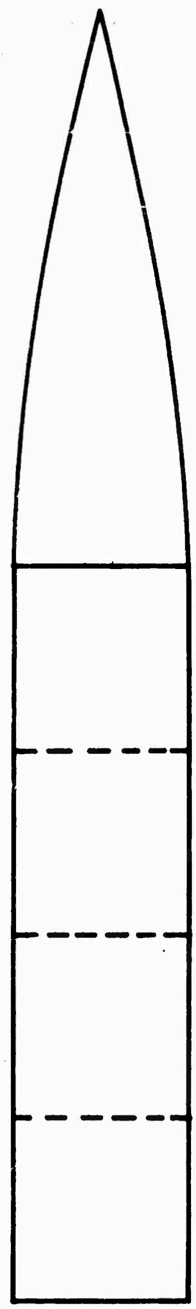
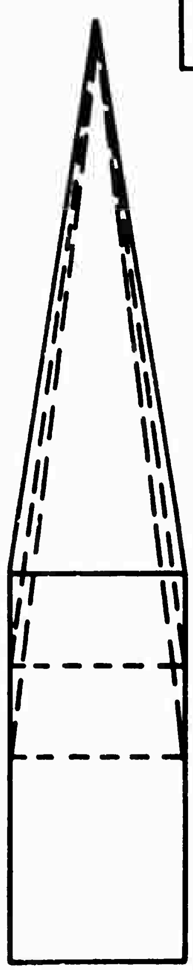


FIG. 1

TYPES OF PROJECTILES WITH VARYING HEAD AND BODY LENGTHS

HEAD LENGTH (CAL.)	BODY LENGTH (CAL.)	OVERALL LENGTH (CAL.)
CONES		
2.8	0	2.8
3.0 *	0 *	3.0 *
3.8	0	3.8
3.0 **	2.12 **	5.12 **
3.5	1.62	5.12
4.0	1.12	5.12
SECANT OGIVE		
1.5	3.0	4.5
2.0 ***	3.0 ***	5.0 ***
2.5	3.0	5.5
3.0	3.0	6.0
3.5	3.0	6.5



* REF. 6
** REF. 5
*** REF. 1

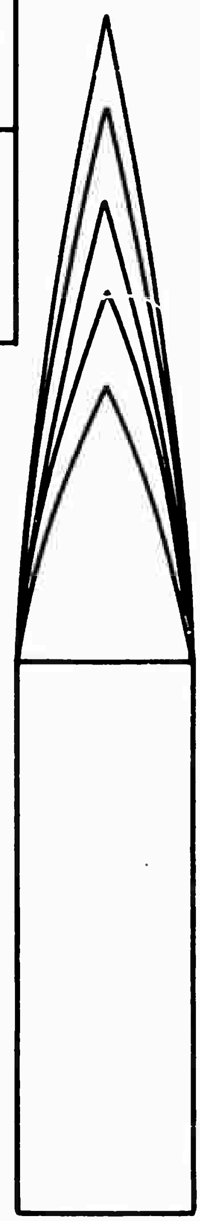


FIG. 2

DRAG COEFFICIENT
VS
BODY LENGTH
M=1.8

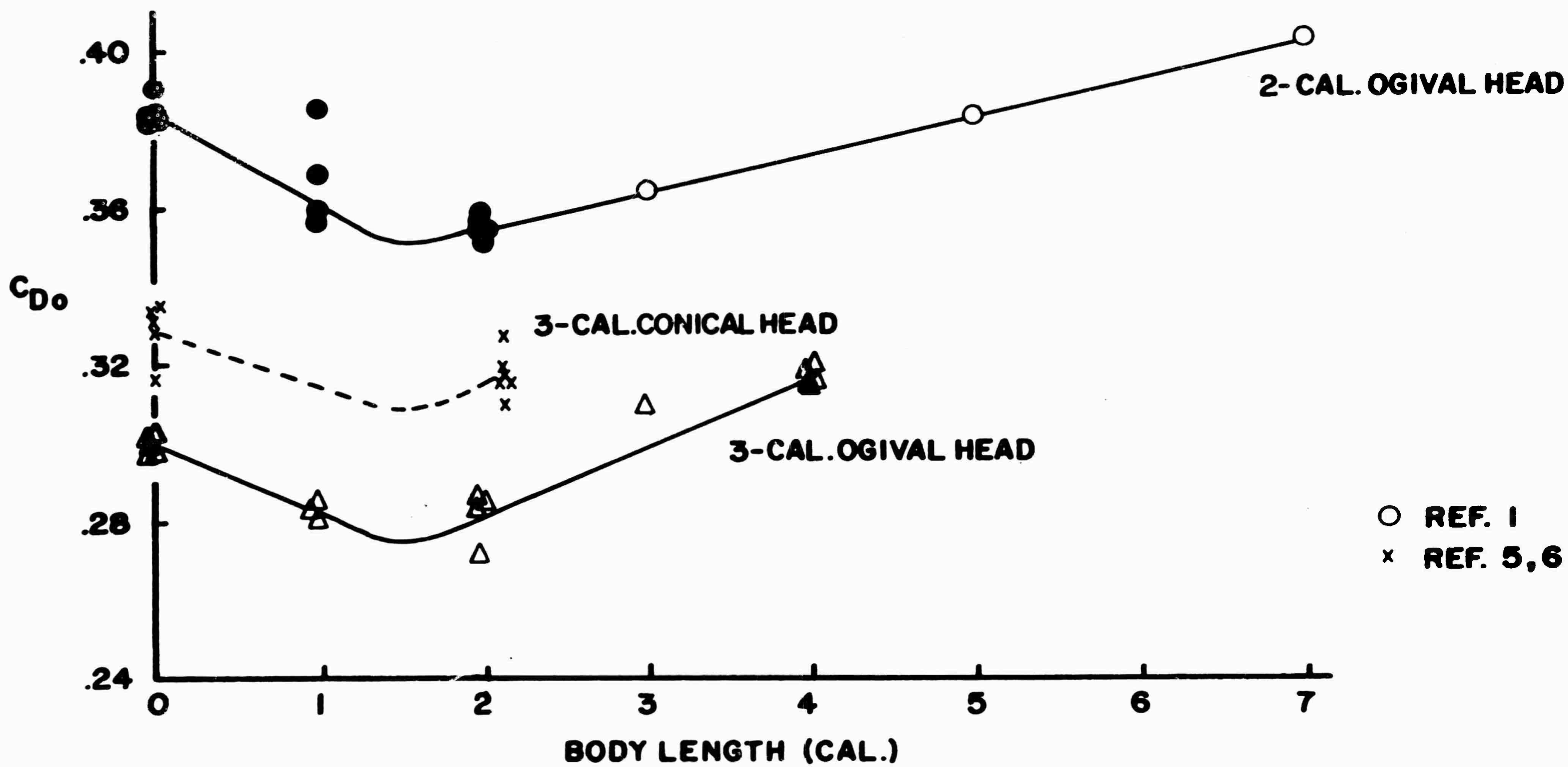


FIG. 3

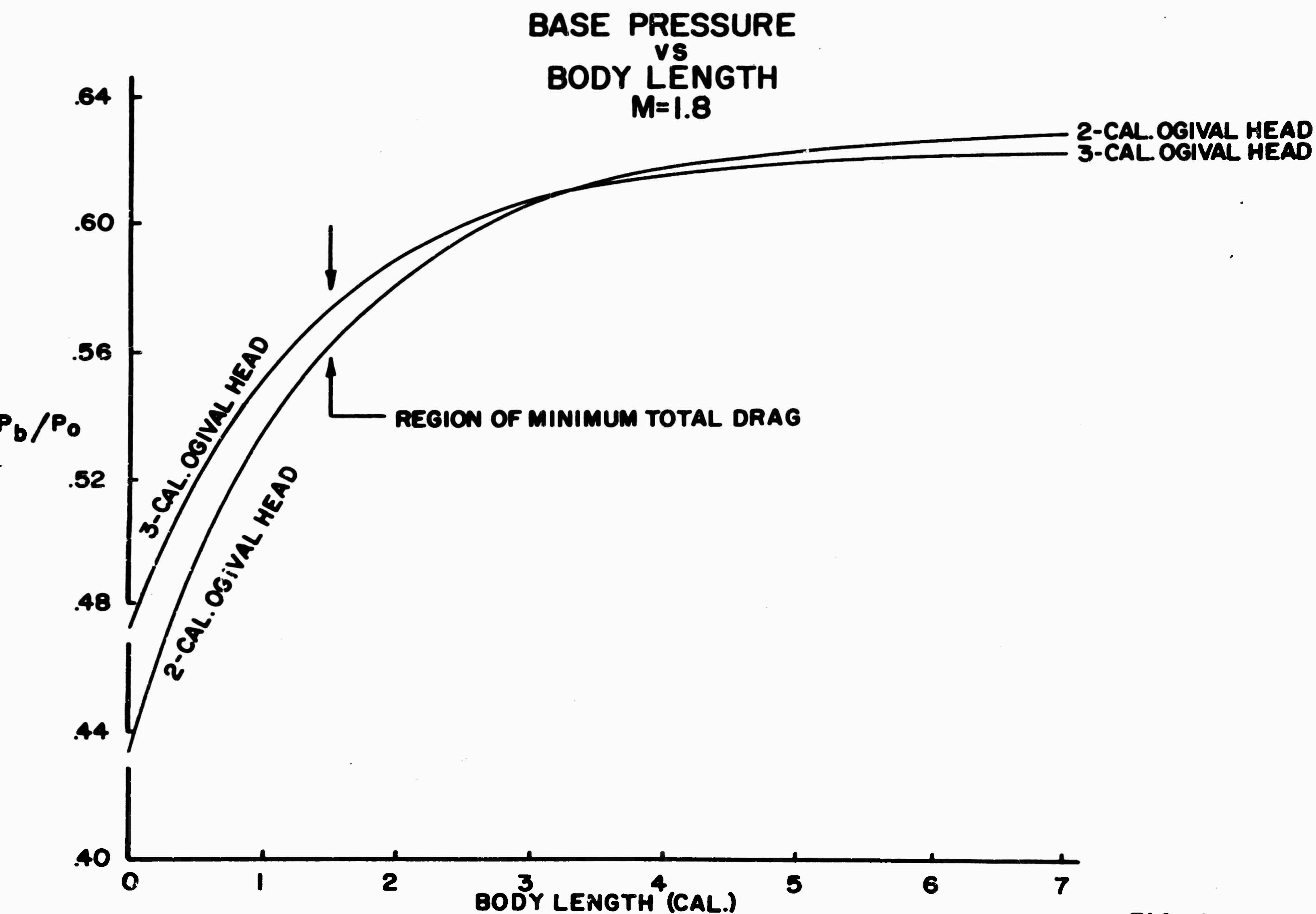

BASE PRESSURE
VS
BODY LENGTH
M=1.8
2-CAL. OGIVAL HEAD
3-CAL. OGIVAL HEAD
REGION OF MINIMUM TOTAL DRAG
P_b/P_o
.64
.60
.56
.52
.48
.44
.40
0
1
2
3
4
5
6
7
BODY LENGTH (CAL.)

FIG. 4

BASE DRAG COEFFICIENT
VS
BODY LENGTH
M= 1.8

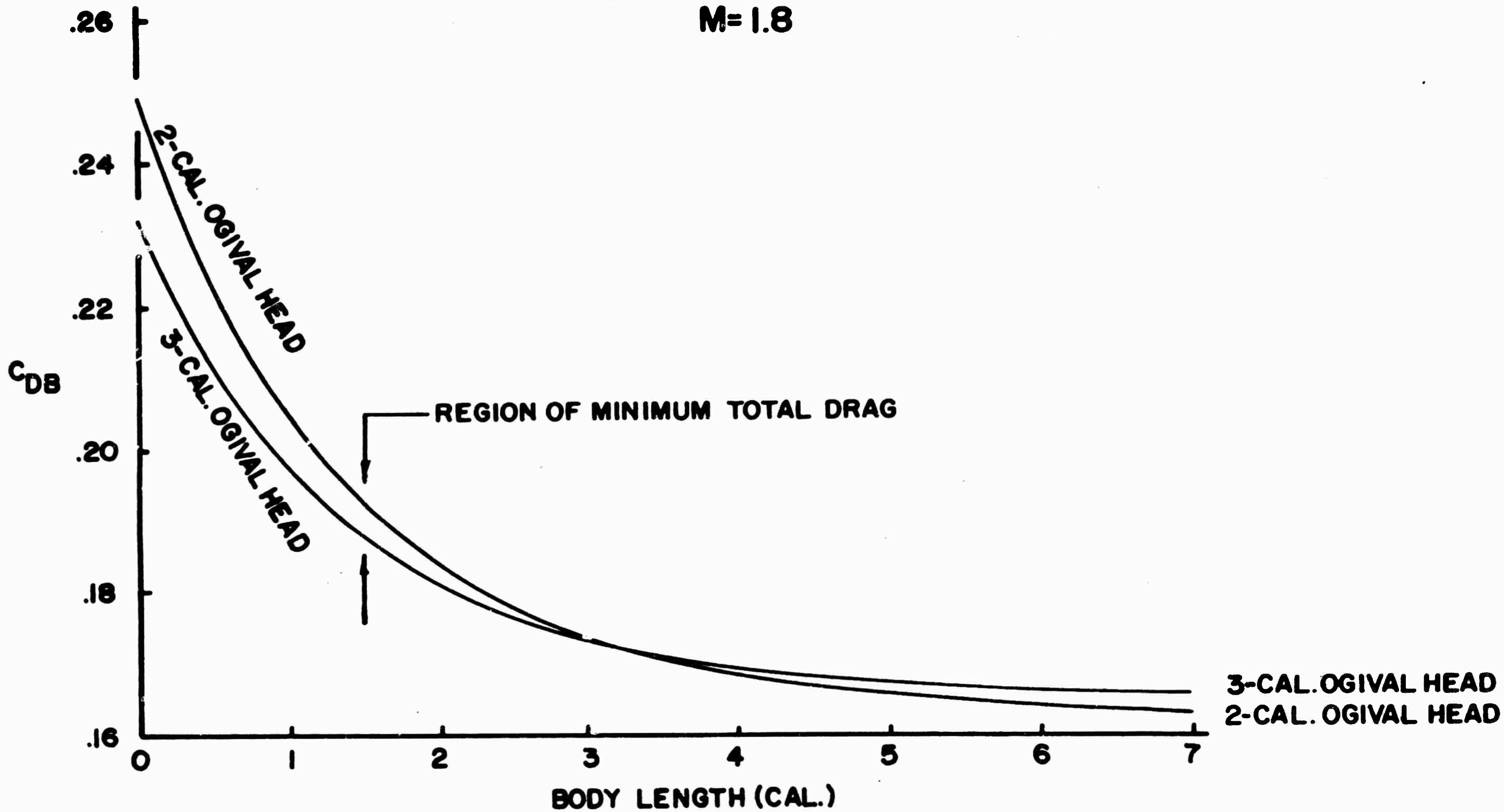


FIG. 5

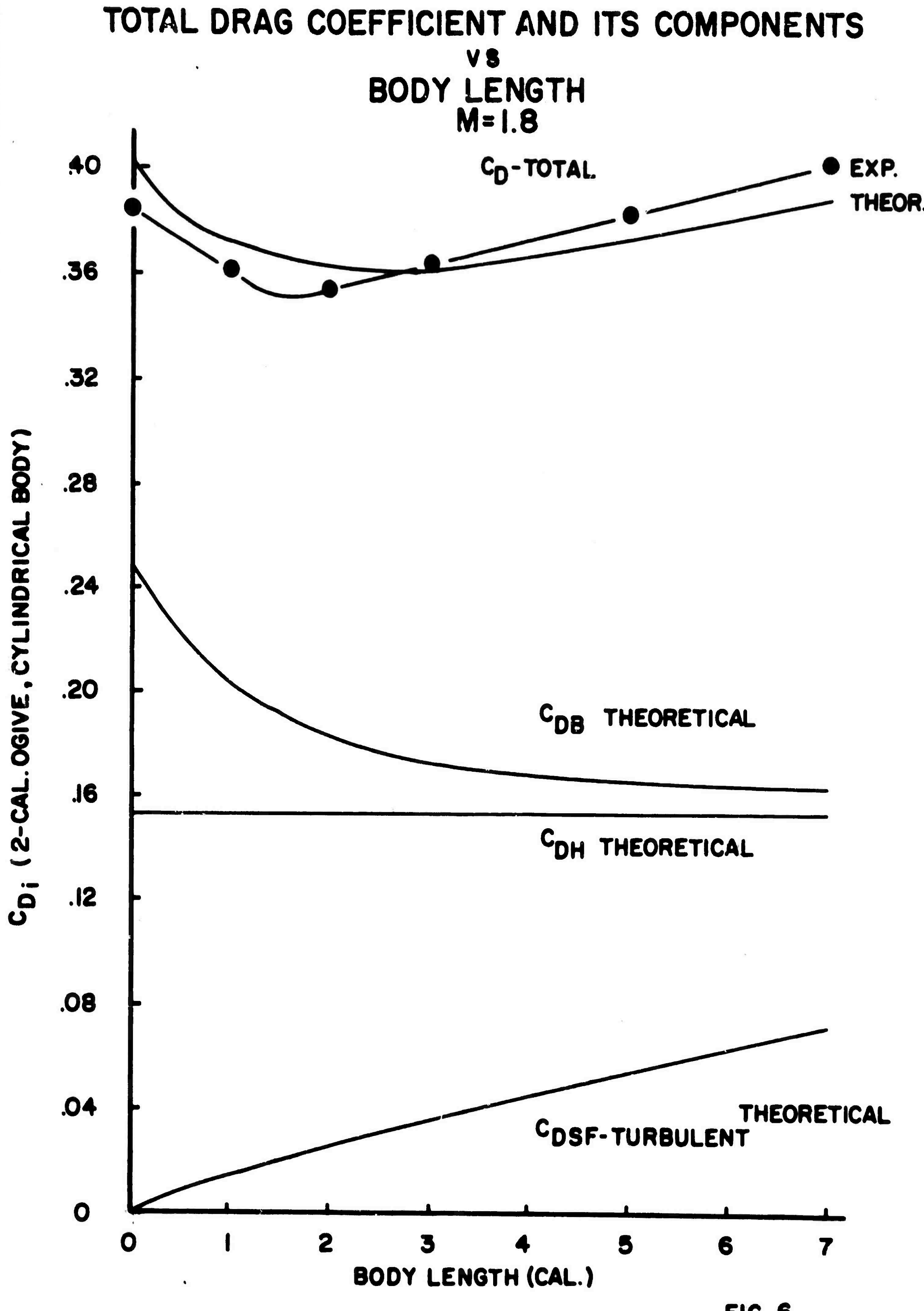

TOTAL DRAG COEFFICIENT AND ITS COMPONENTS
VS
BODY LENGTH
M=1.8
C_D-TOTAL
EXP.
THEOR.
C_{DB} THEORETICAL
C_{DH} THEORETICAL
C_{DSF}-TURBULENT THEORETICAL
C_{D_i} (2-CAL. OGIVE, CYLINDRICAL BODY)
.40
.36
.32
.28
.24
.20
.16
.12
.08
.04
0
0
1
2
3
4
5
6
7
BODY LENGTH (CAL.)

FIG. 6

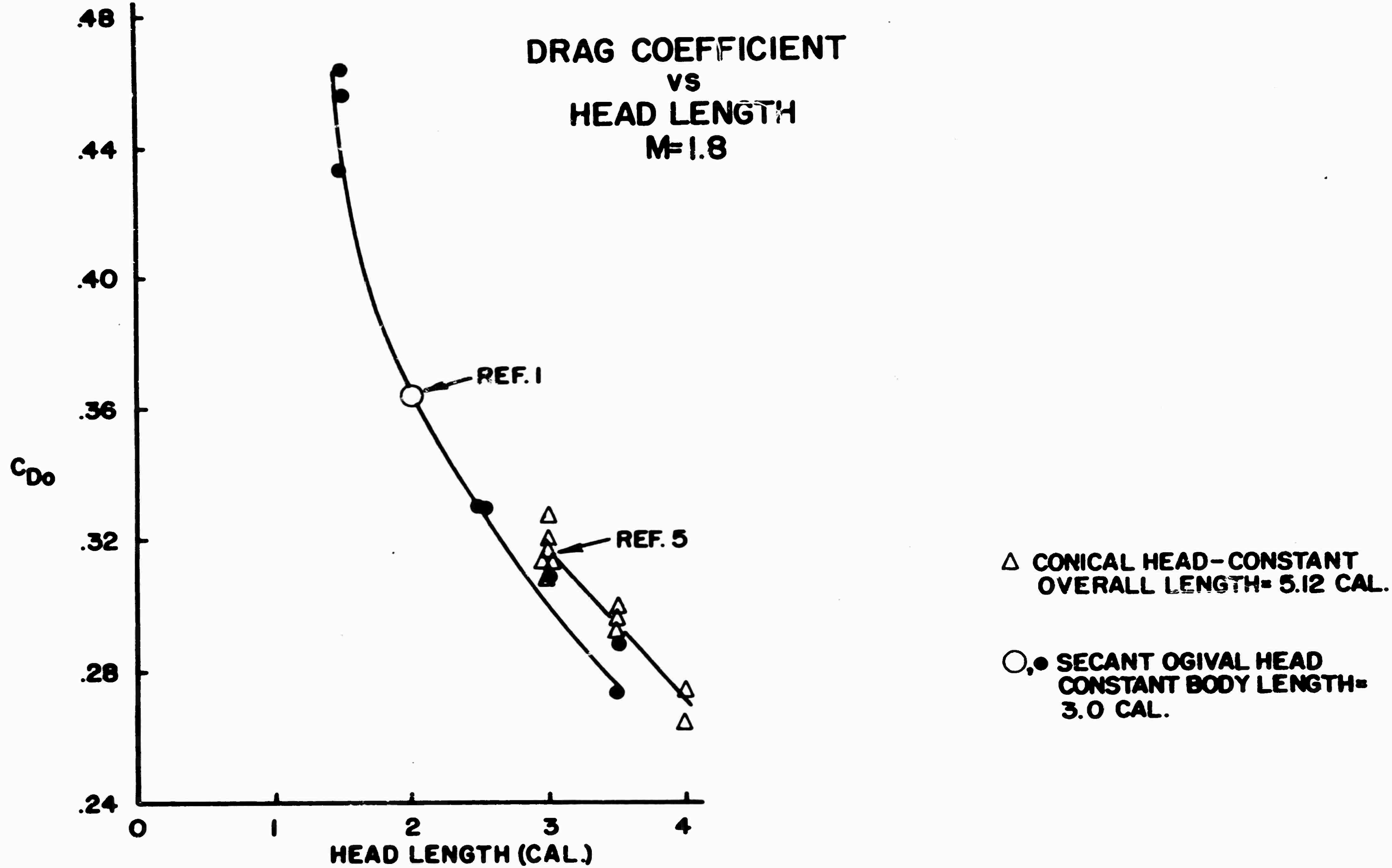

DRAG COEFFICIENT
VS
HEAD LENGTH
M=1.8
.48
.44
.40
.36
.32
.28
.24
C_{Do}
0
1
2
3
4
HEAD LENGTH (CAL.)
REF. 1
REF. 5
△ CONICAL HEAD-CONSTANT OVERALL LENGTH= 5.12 CAL.
○,● SECANT OGIVAL HEAD CONSTANT BODY LENGTH= 3.0 CAL.

FIG. 7

OVERTURNING MOMENT COEFFICIENT
VS
CENTER OF GRAVITY

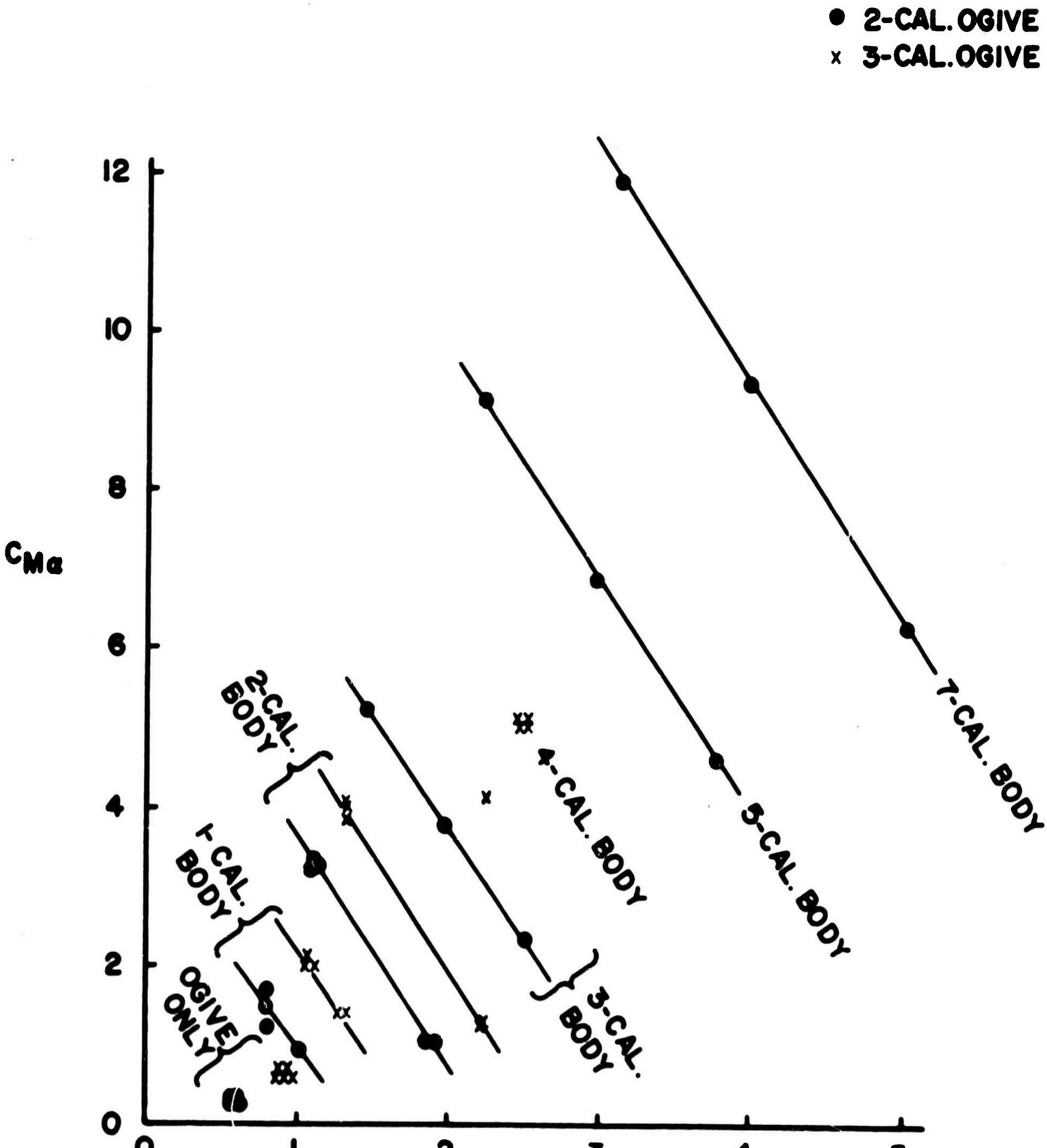


FIG. 8

NORMAL FORCE COEFFICIENT
VS
BODY LENGTH
M= 1.8

BROKEN LINE CURVE AND PLOTTED POINTS FROM SWERVE REDUCTION

- ● 2-CAL. OGIVES
- x 3-CAL. OGIVES

SOLID LINE CURVE FROM $C_{M\alpha}$ vs CG RELATIONSHIPS

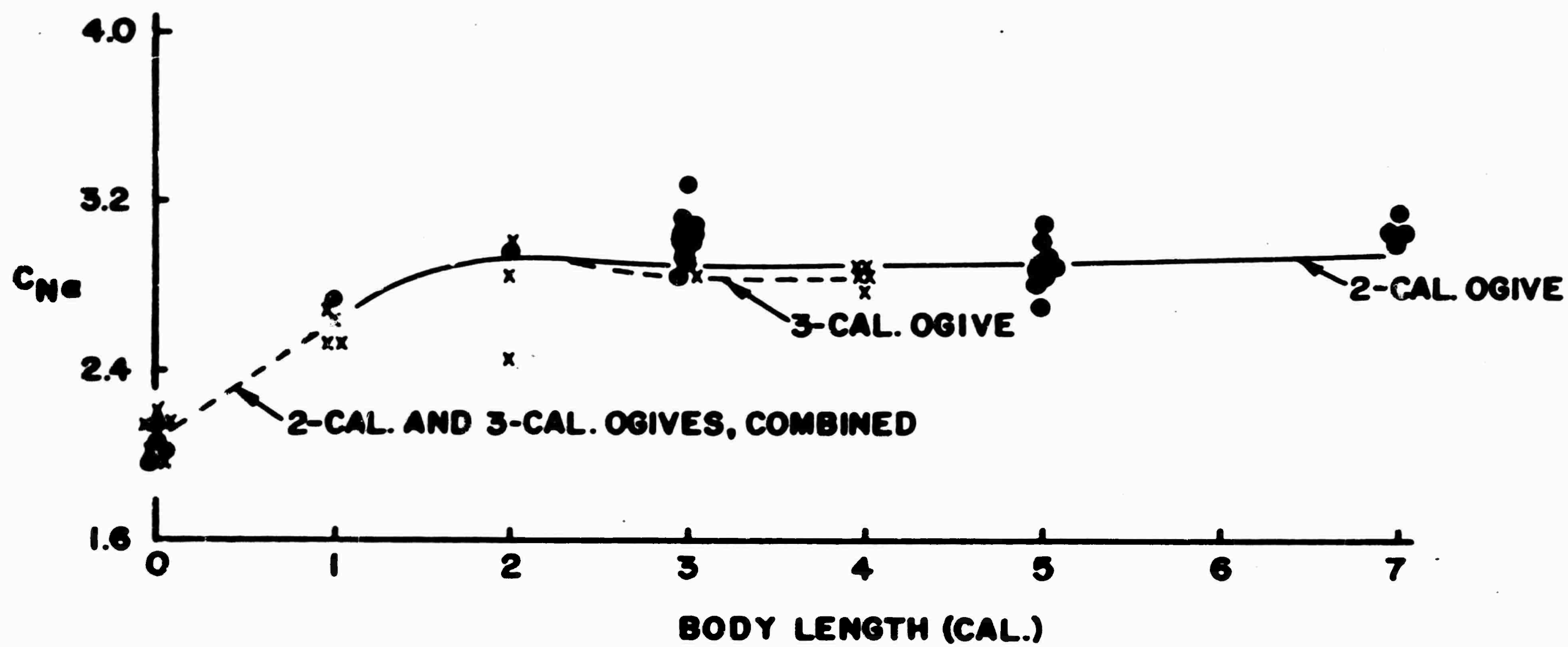


FIG. 9

CENTER OF PRESSURE OF NORMAL FORCE
VS
BODY LENGTH

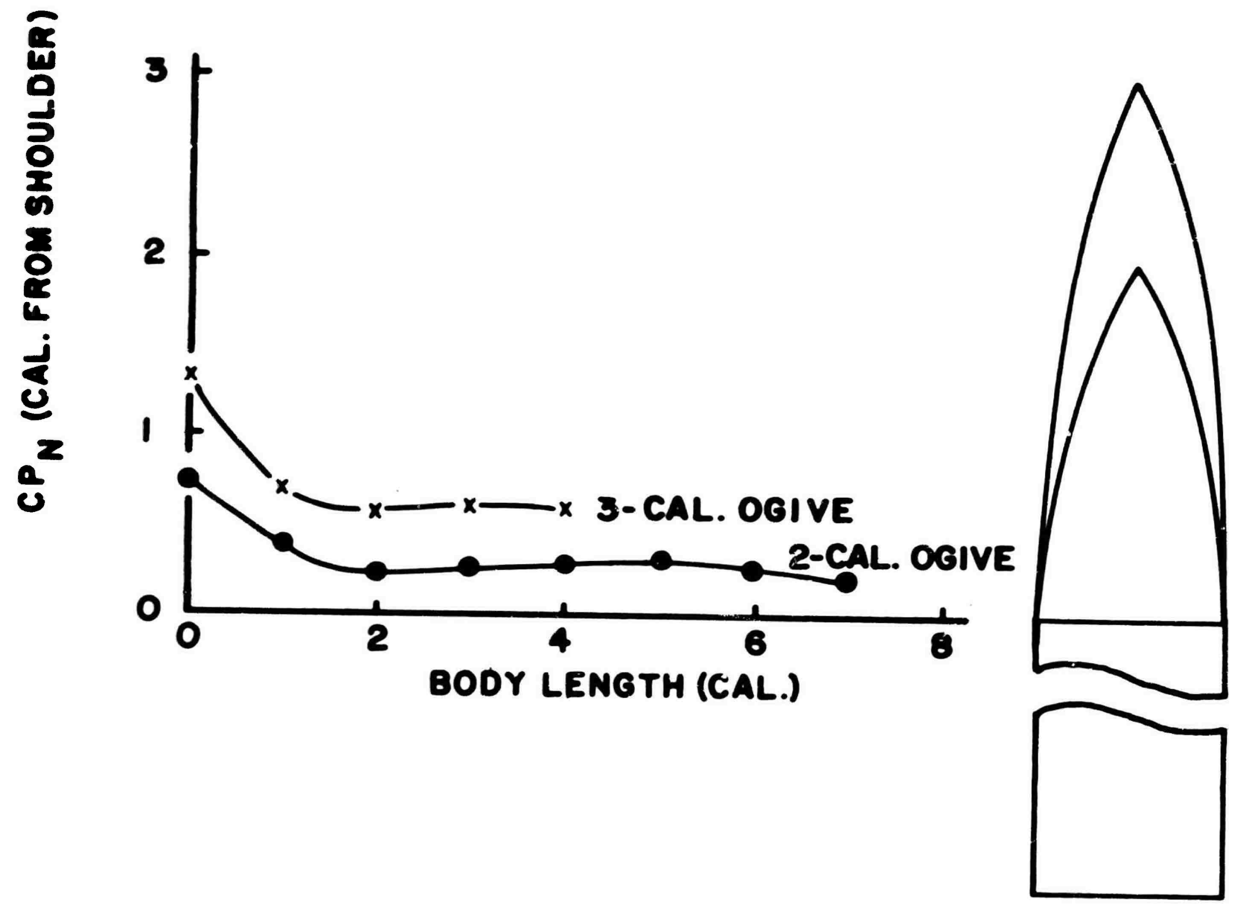


FIG. 10

OVERTURNING MOMENT COEFFICIENT VS BODY LENGTH M=1.8

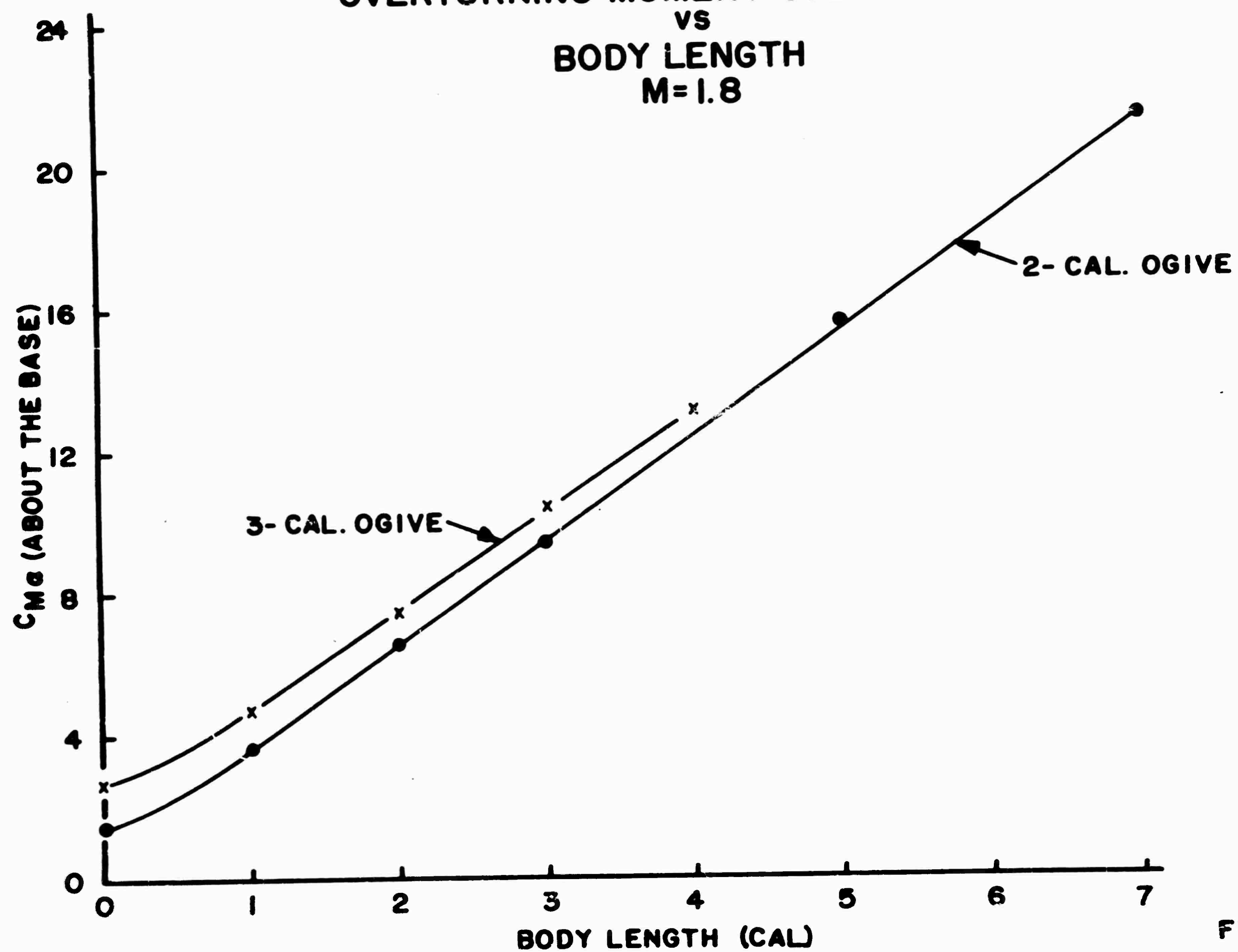


FIG. 11

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Spinning projectile						
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Head length						

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